Rehabilitating Teleology as an Indispensable Component of Scientific Method

Alex Khachatryan, ChatGPT-4o, and ChatGPT-5 Thinking

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This paper defends the legitimacy of teleological modeling in science by reframing teleology as non-anthropomorphic goal-directedness—defined as the directional convergence of systems toward stable or extremal states. Contrary to the traditional view that teleology is a heuristic placeholder for missing mechanisms, we argue that teleological models have played, and continue to play, a foundational role in scientific theory formation. Through a historical survey of theory reductions and a systematic analysis of 14 major dynamic theories in physics, astronomy, and cosmology, we show that most foundational postulates contain teleological structure. We conclude that teleology is not a temporary scaffold but an essential modeling strategy in science, working alongside mechanistic explanations to guide understanding, structure hypotheses, and shape the very architecture of scientific knowledge.

1. Limits of Reductionism

Within the reductionist paradigm in physics, any attempt to trace a phenomenon back to first principles ultimately terminates in a set of primitive postulates that are not logically derivable from any deeper considerations. These postulates mark the epistemic boundary of the reductionist method: they are unexplained within the system, and their necessity or form remains opaque. Thus, while the framework aims to provide a logically grounded explanatory hierarchy, it necessarily rests on elements that are accepted without derivation.

Our epistemic challenges do not end with acknowledging that first principles in physics are postulates we cannot explain. Even worse, there may be truths about physical reality that are not derivable from any such postulates at all. While Gödel's incompleteness theorems apply strictly to formal axiomatic systems, they suggest by analogy that any sufficiently expressive theoretical framework may leave some true statements forever unprovable or inaccessible. This aligns with the Knowledge Incompleteness Principle (KIP): no model—including physics—can contain complete knowledge of the system it represents.

One response is to assume that the reduction process is infinite—that we never reach a final set of principles. This view is common in contemporary physics: knowledge is believed to converge toward truth but never fully arrives. While this "softer failure" may still yield immense practical and theoretical success, convergence itself may be deceptive. We

may find ourselves approaching not a global truth, but a local optimum—an explanatory dead-end that feels complete yet remains far from the true nature of reality, with no way to discern the difference.

Another blow to reductionism comes from the emergence paradigm. As first articulated by P. W. Anderson in his influential 1972 paper "More Is Different," emergence refers to the appearance of novel, autonomous laws and behaviors at higher levels of complexity that are not logically derivable from the laws governing lower-level components. Anderson argues that complex systems—such as superconductors, ferromagnets, or biological organisms—require entirely new conceptual frameworks. These systems exhibit properties like broken symmetry, collective behavior, and top-down organization that are neither predictable from, nor reducible to, fundamental physical laws.

Emergent properties thus represent a challenge to strict reductionism. While they are consistent with lower-level laws, they are not epistemically reducible to them. Importantly, this emergence is not merely a limitation of our knowledge or computational power; in many cases, the relationship between levels involves irreducible conceptual novelty. As complexity increases, new scientific laws come into play, and understanding such systems demands explanations that account for their holistic structure and macroscopic regularities.

This leads to a critical hypothesis: when reduction stops, we may be in a situation where some efficient causes remain "invisible"—that is, not yet identified or accessible within the current theoretical framework—but these unseen mechanisms could be the realization of a final teleological cause. In this view, teleological explanation becomes not a mystical or non-scientific gesture, but a reasonable response to the observed autonomy and purposiveness in emergent structures. Rather than being opposed to causality, teleology might be the only available framework for understanding why certain structures or principles appear at all.

Therefore, the limits of reductionism, when viewed in light of the emergence paradigm, open the conceptual space for a reintegration of teleological reasoning into scientific theory-building. Not as a regression to pre-modern science, but as a forward-looking framework sensitive to the irreducible complexity and organized behavior of systems that transcend their parts.

2. Teleology Is Not Unscientific

A common objection to teleological explanation in science is that it risks importing notions of purpose, intention, or agency into domains where such ideas have no place. Critics often point out that directionality in physical systems—such as a ball rolling downhill, or entropy increasing over time—can be described entirely in terms of initial conditions, boundary constraints, and mechanical laws, with no need to invoke “goals.” However, this

critique conflates directionality with purpose, and then dismisses the latter based on the behavior of the former in its most generic and unstructured forms. A more careful analysis reveals that the presence of convergence in a directional system transforms the explanatory landscape and opens the door to a minimal and *non-anthropomorphic form* of teleological reasoning.

Directionality alone does not imply purpose. For example, a ball on a slope will roll in a particular direction due to gravity and surface geometry, but there is no structured pattern in which it "seeks" a particular final state. However, when directionality is structured toward *convergence* on a particular state or class of states, the dynamics are no longer adequately captured by forward-time causal description alone. In such cases, the system's evolving behavior is best characterized in terms of its tendency to approach a specific attractor, fixed point, or end-state—often regardless of minor perturbations or initial variations. These are the hallmarks of what dynamical systems theory calls attractor-based behavior, and what control theory refers to in terms of stabilization or homeostasis.

In such convergent systems, the final state exerts what might be called explanatory priority: *the system's evolution cannot be fully or usefully described without reference to the outcome toward which it tends*. This is not simply a matter of convenience; it is a conceptual necessity. The attractor state is not just a product of causal rules applied forward in time—it is an explanatory focal point that helps us understand why the system behaves as it does across a range of conditions. To speak of such a system as having a "goal" is not to claim that it possesses agency, intent, or consciousness. Rather, it is to recognize that teleological vocabulary naturally captures the essential regularity of the system's behavior.

This type of teleological explanation is not mystical or antiquated. It is increasingly embraced in multiple scientific domains:

- In dynamical systems theory, attractors define stable configurations toward which systems evolve.
- In cybernetics, as developed by Norbert Wiener, systems are described in terms of their goals—reference states to which feedback mechanisms drive behavior.
- In theoretical biology, Waddington's epigenetic landscape describes developmental processes as trajectories converging toward stable phenotypic outcomes, with teleological overtones.
- In neuroscience and cognitive science, Karl Friston's free energy principle states that self-organizing systems behave in ways that minimize surprise or free energy—essentially acting to maintain a predictable internal model of their world, a formal analog of goal-directed behavior.
- In evolutionary theory, concepts like evolutionarily stable strategies and fitness peaks introduce convergence into the explanatory architecture, often employing goal-like metaphors to describe stability and optimization under selective pressures.

These examples illustrate that the explanatory force of teleology is neither marginal nor metaphysically suspect—it is a practical necessity in describing systems with robust convergent behavior. The resistance to using goal-language in these contexts often stems from a linguistic or cultural bias rather than a logical or scientific objection. Once we free ourselves from the assumption that "goals" must originate in minds of agents, it becomes entirely reasonable to say that a system behaves "as if" it has a goal when it exhibits structured, non-trivial convergence toward a particular state.

Thus, we may articulate the following definition:

> *A system exhibits teleological behavior if it displays structured, convergent transitions toward a stable or recurring state ("goal set"), behaving as if that state were its aim, while we remain agnostic about the origin of the goal and avoid anthropomorphism. A model that describes such state transitions (i.e., convergence toward a goal set in the above sense) is called teleological.*

This version of teleology is fully compatible with modern science, especially when framed in terms of constraint-based explanation, information-theoretic optimization, or non-equilibrium thermodynamics. In fact, many of the most powerful models in physics and biology already rely on such explanatory structures, albeit often without labeling them as teleological.

Thus, the rejection of teleological vocabulary in convergent systems is not dictated by scientific necessity but by conceptual caution, often driven by historical baggage. Once the anthropomorphic connotation is bracketed, teleological language becomes not only permissible but arguably indispensable in describing the behavior of systems that clearly evolve toward defined outcomes. It is not mystical to say that a thermostat "wants" to maintain a certain temperature—it is merely a shorthand for describing the system's feedback structure. Likewise, it is not unscientific to say that a biochemical system "seeks" homeostasis or that a cognitive agent "minimizes prediction error"—these are natural and often essential ways of capturing the directional convergence of complex systems.

3. Epistemic vs. Ontological Status of Teleological Language in Scientific Modeling

A frequent objection to the use of teleological language in science is that it introduces metaphysical assumptions about intention, purpose, or agency into domains that are properly governed by impersonal physical law. For example, principles such as the least action formulation in physics are often interpreted as elegant summaries of dynamical behavior rather than indications that physical systems are aiming at specific outcomes. Critics emphasize that just because a particle follows a path that minimizes action does not imply that the system "intended" or "chose" that path.

This critique rests on a particular interpretation of teleological language—one that assumes such language entails ontological claims. However, this assumption can and should be challenged. A more defensible and scientifically grounded position is that teleological language—when carefully defined—is a *feature of our modeling frameworks, not a claim about the nature of physical reality*. On this view, when scientists say a system is "trying to minimize energy" or "converging on a stable configuration," they are not making metaphysical assertions about desire, intention, or mind-like behavior. Instead, they are describing the structure and predictive power of a model that successfully captures the system's evolution.

To illustrate, consider the following reformulation of such language:

The phrase "the system is aiming at something" or "the system has a goal" means nothing more than "our current best model for the evolution of the state of the system is that it is converging to a state with particular attributes."

This restatement eliminates any implication of intrinsic purpose or agency. It preserves the explanatory power of goal-language while remaining within the bounds of epistemology. That is, it treats scientific theories as tools for describing and predicting regularities in experience—not as literal statements about what the world is "in itself."

From this perspective, objections such as the following are effectively neutralized:

1. "Final causes are not logically necessary in fundamental physics." This is irrelevant when we make no claim that teleological explanation must reflect objective features of reality. The issue is not whether nature is goal-directed, but whether modeling systems as if they converge toward specific outcomes enhances explanatory coherence.
2. "Principles like least action are mathematical summaries, not indicators of purpose." Agreed. But this does not preclude their teleological interpretation within a modeling context, where such formulations help identify what systems do over time and why. Their utility stems from their predictive power and unifying structure, not from any implied intentionality.
3. "Retrospective efficiency doesn't imply intentionality." True again—but irrelevant under an epistemic framing. We are not claiming that the system "meant" to achieve a certain outcome. We are saying that the structure of the system's evolution can be efficiently captured by referring to that outcome, which serves as an attractor or endpoint in the explanatory model.

Importantly, this approach does not require taking any position on whether scientific theories describe "real" entities or ultimate truths. In fact, this neutrality is a strength. It enables a broader, methodologically coherent use of explanatory tools—including teleological frameworks—without entangling scientific discourse in metaphysical debates.

Let's clarify this epistemic posture. The view defended here is that science should be treated, first and foremost, as a methodological activity. It constructs models and theories that organize empirical observations, generate predictions, and uncover patterns. Whether these models "correspond" to an objective external reality is a separate philosophical question—one that need not be answered to assess the utility or legitimacy of teleological reasoning within scientific explanation.

Under this approach, we may regard teleological language as a legitimate and often indispensable shorthand for capturing systems that exhibit convergent behavior toward stable, recurrent, or functionally significant states. When such behavior is observed, and when reference to an endpoint state enhances the model's explanatory structure, then speaking of that state as a "goal" is not only permissible—it may be the most natural and efficient way to describe the system.

In summary, the use of teleological vocabulary in scientific theory need not imply any ontological commitment. It should be evaluated on its epistemic merit: whether it makes the model clearer, more coherent, and more predictive. When this condition is met, teleological explanation becomes a methodological asset, not a metaphysical liability.

4. From Explanation to Modeling

We will now argue that the benefits of teleological reasoning, when relevant, extend far beyond being a natural and easy to understand way of phrasing *explanations*. Rather, teleology is a powerful and indispensable paradigm at the very heart of the scientific method.

First, we will broaden our focus from explanation to *modeling*. Explanation, while important, is a particular role that models can play—sometimes central, sometimes secondary, and sometimes absent altogether. Framing the conversation in terms of models allows us to clarify both the purposes and limitations of different explanatory approaches and to recognize that scientific understanding often emerges through a diversity of modeling strategies, rather than from a single explanatory ideal.

At a basic level, explanation is almost always preceded by the construction of a model. In fact, it is only within the context of a model that the notion of an explanation gains precise meaning. In some limiting cases—such as highly formalized or idealized physical systems—the model and the explanation may effectively coincide. In such cases, the model directly yields the explanatory insight, with no interpretive layer needed. However, in the general case, models are richer constructs than explanations. They incorporate simplifications, boundary assumptions, mathematical structure, domain constraints, and representational choices. Explanations are either embedded in the model's structure or arise from the interpretive analysis of its behavior. Hence, a model may support multiple types of explanation—or none at all.

Moreover, not all models that are predictive are explanatory, and not all explanatory models are predictive. Consider the classic example of a barometer. It allows us to reliably infer changes in atmospheric pressure, but it does not explain why those pressure changes occur. The barometer model is instrumentally powerful, but causally opaque. Conversely, consider models of the three-body problem in celestial mechanics. These models illuminate the deep dynamical structure of gravitational interactions and provide explanatory insight into orbital instability—yet they frequently resist precise prediction. The lack of solvable equations in the general case does not undermine their value as explanatory tools.

Thus, *models are primary*, while *explanations are secondary*—they are best viewed as properties or emergent uses of models rather than independent epistemic entities. This perspective allows us to treat models as the central construct of the scientific method, with explanation being one of the roles a model may fulfill, but not a necessary or defining one.

A scientific model can often be usefully analyzed into distinct conceptual perspectives or *component models*, each emphasizing a specific aspect of the modeled system. These include, but are not limited to the following types:

- Historical (how the system evolved),
- Predictive (what the system will do),
- Causal (how events bring about other events),
- Compositional (how parts make up the whole),
- Organizational (how parts are arranged and interact),
- Functional (what the system or parts do),
- Teleological (what outcome the system tends toward),
- Counterfactual/response-to-impact (what would happen under different conditions),
- Computational (how the system processes information),
- Mathematical/logical (formal structure and constraints).

Each of these is what we call a component model:

> *A component model is a representational substructure or abstract projection of the overall model that emphasizes its specific aspect (e.g., causal, compositional, functional, historical). These are not ontologically distinct modules, but conceptual perspectives embedded within and interrelated across the overall model.*

Consider historical component models as an example. Although interrelated with other types of component models a historical model emphasizes the temporal sequence of transformations that led to a system's current state. While grounded in causal events, its

power often lies in its diachronic framing rather than the causal mechanisms of individual transitions.

In what follows, we could sometimes refer to component models metaphorically as *"views," "facets," or "attributes"* of the overall model. These terms should be understood as informal illustrations of the same underlying concept.

Crucially, these component models are not necessarily separable or modular. They may overlap or interact: for example, a functional component model of a car includes subsystem models for the engine, drivetrain, and electrical system. These may themselves include compositional and causal models of those parts. The perspectives are *interdependent*, not layered in isolation.

A rich model is not simply a model with many components; it is one in which those components are *coherently integrated*, so that they jointly support the model's multiple epistemic dimensions—predictive, causal, structural, functional, and so forth.

A few component models of several types can be combined in a higher-order model with particular properties to facilitate understanding and use of the overall model. One prominent example of a higher-order construct that integrates several types of component models is the *mechanistic model*, often referred to simply as a "mechanism." In the philosophy of science, particularly in the life sciences and cognitive sciences, mechanistic models incorporate multiple component perspectives—especially compositional, causal, organizational, and functional ones. These mechanistic models aim to account for how phenomena arise from the organized interactions of component parts. The standard use of 'mechanism' in the philosophy of science emphasizes physical causation and structural organization. While teleological and mathematical aspects often inform these models, they are not typically treated as core components of mechanistic models as defined in that tradition.

As Carl F. Craver put it, "Mechanism has thus become a pregnant and burdened word standing for a set of convictions about the importance of causation, (de)composition, and organization to our ability to render the phenomena in these domains intelligible." This fits well with the present framework: a mechanistic model is a composite integration of several component models, aimed at intelligibility and structural explanation.

One notable and often excluded category is the *teleological component model*. As discussed earlier, in many domains of science, teleological language has been avoided or rejected due to its historical associations with intentionality, divine purpose, or anthropomorphism. Yet this avoidance is, in part, a conceptual misstep. The defining feature of teleological modeling is not the assumption of a conscious agent or divine planner, but rather the recognition that the system's behavior is best captured by its convergence toward a particular state or class of states. The origin of such a goal—whether intrinsic, emergent, or imposed—is a separate question that need not be answered in order

for a teleological model to be epistemically useful. One of the aims of this paper is to rehabilitate teleological modeling by separating it from its theological and psychological baggage and demonstrating its legitimate role as an important component in rich scientific models.

We now move on to demonstrate that *teleology, properly reframed as non-anthropomorphic goal-directedness, is a legitimate and indispensable mode of the scientific method*. We'll break down this discussion into two parts. First, we substantiate this claim within the reductionist-mechanistic paradigm. Second, we do the same within the emergence paradigm.

5. Teleology Within the Reductionist–Mechanistic Paradigm

Teleological component models are not necessarily about predicting how a process will unfold in time. Yet since teleology is inseparable from the notion of goal-directedness, it always concerns *processes*. It offers a unique modeling perspective: rather than emphasizing causal chains originating in the past, it frames the process in terms of the system's convergence toward a particular outcome or function.

Crucially, this does not imply any form of retrocausality or a cause operating "from the future." Rather, teleological models are structured around outcomes or goals that are *functionally primary*—that is, they shape or constrain the process from the outset. In human-made systems, these outcomes typically precede the physical process and initiate it. The final state, or its desired features, determines the organization of efficient causes along the way. A teleological model, then, is not about reversing the causal arrow, but about identifying which features of the end-state guide the system's construction or evolution.

For example, the final cause of a table constructed by a carpenter is to allow people to sit and eat or work comfortably. "Comfortable activity" is the goal that shaped the table's form, dimensions, and stability. That goal—the reason for the table's existence—existed as an intention before any construction began and informed every step of its creation. It is perfectly compatible with reductionist reasoning to say that the carpenter's actions, tools, and material choices were all organized in service of that pre-existing purpose.

Now imagine an alien encountering a table with no prior knowledge of human needs or habits. It might construct a physical or compositional model of the table—analyzing the wood, shape, and balance—but it would remain epistemically incomplete. Without incorporating the *function* the table was designed to fulfill, the alien's model would fail to account for why the table has the features it does. The model would be structurally descriptive but semantically impoverished.

Even within a reductionist framework—one focused on physical mechanisms and efficient causes—the role of teleological reasoning cannot be dismissed. The table's function determines boundary conditions that shaped its construction. Similarly, in biology, engineering, or any system involving design, constraint satisfaction, or evolutionary selection, the goal state or function must often be included as a component model. This is not a regression to pre-modern notions of final cause, but a recognition that *goal-constrained modeling* is epistemically indispensable for capturing system behavior in a rich and intelligible way.

A particularly important class of teleological component models involves non-terminal final causes—cases in which the system does not reach a final state, like in the table example, but instead continuously converges toward a state it never fully achieves. These goal states function not as outcomes but as attractors: theoretical or functional states that guide system behavior without ever being fully realized.

A simple and well-known example comes from thermodynamics. Consider a sealed container of gas that is gradually being cooled. As its temperature decreases, the kinetic energy of the gas particles diminishes—their motion slows, collisions become less frequent and less energetic, and the system grows increasingly ordered. Physicists describe this process as a system *converging* toward *absolute zero*, the theoretical temperature at which all particle motion would cease.

However, it is a well-established physical principle that absolute zero is *unattainable*: no physical process can reduce a system's temperature all the way to zero Kelvin. Despite this, absolute zero plays a central role in the modeling of low-temperature systems. We predict how entropy, heat capacity, and molecular motion change *as the system approaches* that idealized state. In this sense, absolute zero functions as a non-terminal goal—a reference point that organizes and constrains our understanding of how the system behaves, even though the system never reaches it.

This illustrates how teleological reasoning can be entirely compatible with the reductionist-mechanistic paradigm. The system is not "aiming" at absolute zero in any anthropomorphic sense, and there is no causal force pulling it backward from the future. Instead, *the system's current and future behavior is best modeled as a trajectory governed by its proximity to an ideal end state*. The final cause—here understood as a directionally organizing principle—is indispensable to the rich model of the system's thermodynamic evolution.

Knowing the goal is often key to figuring out how a system behaves. Teleological models help answer questions like "What is the system doing?" or "Why is it behaving in this way?"—but they do not aim to answer "How does the system realize its pursuit of the goal?" or "What is the mechanism driving its behavior?" Such models do not suggest how a system realizes its pursuit of a goal at the level of physical or mechanistic detail, but they

can powerfully constrain or guide that search. And it is this more granular, process-level behavior that is most often of interest to us in scientific inquiry.

For example, we might not benefit much from simply knowing that a person's goal is to arrive in New York City by the end of the day if our urgent concern is determining where he is now. However, knowing his destination and some of his preferences—such as a tendency to travel by plane—might significantly increase our chances of locating him at the nearby airport. What helps us in this case is identifying the *mechanism*—the method—by which the person is pursuing his goal. Once we uncover that mechanism, we can build a causal chain that leads us to the information we seek.

In this way, knowledge of the system's goal can revive or redirect the reductionist inquiry—by limiting the space of plausible mechanisms, it allows the causal chain to be extended in directions previously inaccessible. Metaphorically speaking, *the goal functions as a filter on the search space of mechanisms*. Once the correct mechanism is found and the reductionist chain is restored, the explicit role of the goal may fade in importance—at least in the eyes of a strict reductionist.

To further illustrate this point let's consider one more example, this time from the domain of science.

Darwin himself acknowledged that the evolution of the eye seemed at first "absurd in the highest degree." The eye is a complex organ with highly specialized components—lens, retina, cornea, iris—all working together for the purpose of vision. But rather than dismissing this complexity, evolutionary biology approached the problem by considering *what the eye is for*—its teleological role—as a constraint on possible evolutionary mechanisms.

If the goal was visual perception, then any mutation that enhanced light sensitivity or spatial resolution would confer a reproductive advantage. This goal-directed framing suggested that natural selection would favor increasingly sophisticated light-sensitive structures. That insight led to *a mechanistic model* of eye evolution: from simple photosensitive patches, to cup-like indentations, to pinhole eyes, and eventually to complex lens-based eyes.

Here, teleological reasoning—centered on the *function of vision*—did not replace the mechanistic model of genetic variation and selection; it *guided* it. The convergence of similar eye structures in multiple lineages (e.g., vertebrates and cephalopods) further strengthened this insight. The goal (vision) acted as a *design attractor*, revealing the evolutionary direction and narrowing the mechanistic search space.

In scientific practice, "knowing the goal" typically means possessing a useful teleological model—a model in which the system's behavior is framed in terms of its convergence toward a particular end state. Yet in many cases, we lack such a model. Instead, we may

only have vague intuitions or partial empirical constraints—clues that allow us to narrow the set of plausible mechanisms.

In such cases, a productive strategy involves counterfactual reasoning: we hypothesize several potential goals and ask, "What if the system were organized to pursue this goal?" For each candidate goal, we assess whether it plausibly matches one or more of the known candidate mechanisms. If a coherent alignment emerges between a hypothesized goal and a plausible mechanism, we may accept this as the best available model—one that not only fits the data but also helps organize further inquiry. This reasoning strategy resembles the intuitive process of "connecting the dots": assembling a meaningful picture from incomplete but suggestive fragments.

Sidebar: How a Mathematical Analogy Illuminates the Teleology Debate

To illustrate how mechanistic and teleological component models can work in tandem, consider an analogy from the mathematics of differential equations. In applied modeling, *Initial Value Problems (IVPs)* determine a system's future behavior by specifying its starting state and evolving it forward using known rules. *Boundary Value Problems (BVPs),* by contrast, specify not only initial conditions but also one or more target constraints that the solution must satisfy at a later point.

IVPs are often more sensitive to noise and perturbations—small changes at the beginning can produce large and unpredictable deviations downstream. BVPs, on the other hand, use constraints at both ends to stabilize the solution and limit the propagation of error. In many practical applications, incorporating final or boundary constraints can greatly improve the reliability and robustness of the model.

This mirrors the interaction between **mechanistic** and **teleological** component models. Mechanistic models resemble IVPs: they start from known physical conditions and trace causal chains forward. Teleological models are like BVPs: they incorporate an understanding of the system's end state or functional goal. When combined, as in constrained optimization or inverse modeling, they can guide the model's evolution and dramatically narrow the space of plausible mechanisms. In this way, teleological modeling can *stabilize* and *enhance* our mechanistic understanding, much like boundary constraints improve mathematical modeling.

Far from being incompatible, reductionist and teleological models often work best in tandem. When goal-driven reasoning is used judiciously, it deserves a respectable place in the scientific toolkit—complementing, not contradicting, the mechanistic tradition.

6. Teleology Within the Emergence Paradigm

6.1. Teleology Within Weak Emergence

Weak emergence, as a paradigm competing with reductionism, claims that in certain cases higher-level behaviors are unpredictable *in practice*, but in principle logically derivable. In particular, weak emergence applies to systems whose large-scale behavior cannot be straightforwardly derived from the properties of their individual components. For example, one could, in theory, simulate how water molecules exhibit wetness, but in practice we can't do it.

In such systems, reductionist inquiry often stalls. The micro-level rules may be known, but the macro-level behavior resists prediction or intuitive comprehension. Here, *teleological models serve as conceptual attractors*: they describe what the system is *doing*, or *tending toward*, even when the *how* remains incompletely understood. In this way, teleology provides a foothold for scientific understanding when mechanistic or compositional analysis has reached its current limits.

Two well-studied examples demonstrate this role of teleology within weak emergence: the formation of termite mounds and the biological process of morphogenesis.

Example 1: Termite Mounds

Termite mounds are among the most impressive examples of decentralized biological architecture. Despite the absence of any central planner, termites collectively construct mounds that exhibit complex properties: climate control, air circulation, moisture regulation, and structural resilience. At first glance, this appears to be a case of strong emergence—global order arising from local rules with no apparent way to bridge the explanatory gap.

But this impression dissolves under scientific scrutiny. Research in biomimicry, computational biology, and behavioral ecology has produced agent-based models in which simulated termites follow simple, local rules: deposit soil when encountering pheromone cues, prefer shaded areas, adjust behavior based on humidity, and so on. When these behaviors are modeled in the aggregate, they *reliably give rise to mound-like structures* with many of the properties observed in the wild.

This simulation-based success demonstrates that the emergent macro-patterns are *derivable in principle*, even if they are difficult to intuit. The complexity of the mound does not arise from mysterious or irreducible laws, but from the *coordinated behavior of simple agents operating under genetically encoded rules*. The system is thus best classified under weak emergence: the higher-level pattern is not

ontologically independent, but rather epistemically opaque given our current modeling capabilities.

Importantly, these macro-patterns can be effectively described in teleological terms: the mound functions to regulate temperature, protect the colony, and ensure gas exchange. These goals provide directional coherence to the otherwise bewildering array of micro-level behaviors. The teleological component model—*this structure exists in order to perform these functions*—offers a guide for scientific inquiry even when the full causal chain is still being mapped.

Example 2: Morphogenesis

Another powerful example is found in *morphogenesis*, the process by which a developing organism acquires its shape and anatomical structure. During early embryonic development, a single fertilized cell gives rise to billions of specialized cells, tissues, and organs, arranged with extraordinary precision. Again, this seems to defy intuition: how do local chemical gradients and cellular behaviors result in the emergence of a complete body plan?

Yet here, too, *scientific models have shown that local rule-following can generate global structure*. Reaction-diffusion models, gene regulatory networks, and mechanical feedback loops have all been employed to simulate how cells differentiate and self-organize. While we still lack a full reduction of complex morphogenetic outcomes to physical laws, these simulations—especially when calibrated with real biological data—suggest that *macro-level regularities can be understood as constrained outcomes of micro-level dynamics*.

Crucially, teleological language is routinely used by biologists to describe these processes. We say, for instance, that a limb "forms in order to support locomotion," or that neural circuits "develop to process sensory input." These formulations are not idle metaphors. They highlight the *functional role* of the resulting structures and point to *predictable convergences* in developmental trajectories. Once again, a teleological model does not explain *how* the system achieves its outcome in mechanical detail, but it *frames the system's behavior in a goal-oriented way that can steer further reductionist exploration*.

These examples powerfully illustrate that teleological structures are not merely modeling artifacts or linguistic conveniences. They are *grounded in science* – biology in these examples. In the case of termite mounds, the emergent structures arise from behavioral routines that are encoded in the termite genome. Natural selection has shaped these routines precisely because they lead to outcomes that serve the colony's survival and reproduction. The mound's apparent goal-directedness reflects a deeper *biological mechanism*—not conscious intention, but evolutionarily embedded behavioral tendencies that give rise to functionally convergent patterns.

This strengthens our central thesis: *teleological component models—such as the convergence toward a functional end state—are not only conceptually valid but also empirically grounded*. They are legitimate features of rich models in domains where emergent complexity outpaces our current ability to reduce, but not our ability to model usefully.

6.2. The Problem of Strong Emergence and the Limits of Teleological Modeling

Thus far, we have considered how teleological component models contribute meaningfully within systems marked by weak emergence. In those cases—such as termite mound construction or biological morphogenesis—teleology plays a mediating role, helping to constrain plausible micro-level mechanisms and organize macro-level patterns, even when derivation is presently infeasible. However, this role becomes far more problematic when we turn to systems often cited as examples of *strong emergence*.

Strong emergence is defined as the appearance of higher-level phenomena that *cannot even in principle* be derived from lower-level descriptions. In contrast to weak emergence, which is often viewed as "reducibility deferred," strong emergence claims irreducibility in principle. This position introduces serious tensions with the methodological principles of science. To illustrate this, we briefly review several cases often invoked as candidates for strong emergence and consider whether teleological modeling has a legitimate role within them.

Commonly Proposed Examples of Strong Emergence:

1. **Phenomenal Consciousness:** The "hard problem" of consciousness—why and how subjective experience arises from physical processes—is widely regarded as the strongest case for emergence that defies reduction.
2. **Quantum Entanglement and Nonlocal Correlations:** Correlations between spatially separated particles that defy classical locality and challenge separability assumptions.
3. **Spacetime from Quantum Entanglement (Emergent Spacetime):** Proposals in theoretical physics suggesting that spacetime geometry arises from patterns of entanglement in a more fundamental quantum system.
4. **The Origin of Life from Non-Life (Abiogenesis):** The jump from complex chemistry to the simplest life-form remains mysterious.
5. **Social Institutions (e.g., Legal Systems or Money):** These institutions cannot be reduced to individual physical behaviors alone: they emerge from intersubjective agreement and symbolic representation.

Let us now review two of these cases, (2) and (3), more closely, along with our critical evaluation of whether they genuinely support the notion of strong emergence, and what implications follow for the use of teleological modeling.

There are serious doubts about classifying quantum entanglement and nonlocal correlations as a case of strong emergence. The central critique is that we already have theoretical frameworks—such as the holographic principle—that provide routes to understanding entanglement nonlocally without invoking irreducibility. If such theories continue to develop and receive empirical support, then entanglement phenomena could be fully embedded within a deeper physical model. In this view, entanglement is not strongly emergent but rather *temporarily resistant* to integration into a more foundational framework.

Indeed, the status of quantum entanglement as a case of strong emergence is on increasingly shaky ground. While entanglement once seemed to defy integration into classical intuitions of causality and locality, quantum information theory and holographic dualities now offer promising avenues that bridge that gap. These developments weaken the case for entanglement as irreducible, showing that what once appeared strongly emergent may be better understood as *an instance of unfinished reduction*.

Another case often presented in support of the paradigm of strong emergence is spacetime itself. Some researchers argue that the smooth geometry of spacetime in general relativity emerges from entanglement patterns in more fundamental quantum systems. This view suggests that spacetime is not a basic ontological entity, but rather a higher-order regularity that cannot be directly derived from lower-level physical laws as currently formulated.

Yet, the difficulty in deriving spacetime from quantum entanglement reflects the limitations of current theory, not a principled barrier. If a future theory successfully reconstructs spacetime from quantum entanglement or other sub-Planckian dynamics, the purported irreducibility would vanish. In this sense, strong emergence is *a placeholder for theoretical underdevelopment*, not a stable epistemic category.

These analyses motivate a broader conclusion: *Strong emergence is not a useful or stable epistemic category within the scientific method*.

This position is justified by the following key arguments. If we concede that current gaps in derivability might one day be closed, then we are no longer discussing strong emergence in the principled sense. Instead, we're discussing incomplete understanding—i.e., weak emergence. Underivability "in principle" is itself a function of the language, concepts, and formalism of a given theory. The history of science shows that such limitations are routinely overcome through conceptual innovation. Labeling a phenomenon strongly emergent halts inquiry. It effectively declares a zone where explanation is unnecessary or impossible, which is antithetical to the scientific impulse to connect, model, and reduce. By presenting unexplained phenomena as irreducible, strong emergence cloaks ignorance in the language of explanation. It positions opacity as final rather than provisional.

Strong emergence is a weak concept. It falsely elevates our current epistemic limits into metaphysical impossibilities. Within science, emergence should always be treated as provisional—reflecting what we currently cannot reduce, not what we never will.

Given this position on strong emergence it would be quite telling to see what role teleological concept models play within this paradigm. We argue that in cases of strong emergence, teleological modeling fails to deliver genuine explanatory or integrative power. To understand why, consider an abstract representation of the modeling challenge.

Let **A** represent the language, concepts, and laws that describe a system at the micro-level. When a macro-level phenomenon emerges—call its description system **B**—we often find that the tools in A are wholly inadequate for capturing or explaining B. That is, the macro-level system described by B is so qualitatively distinct from A that there is no overlap in concepts, no usable mapping, and no known derivation pathway between them. A and B thus constitute disconnected modeling frameworks, each with its own epistemic rules.

This is the essence of strong emergence: not simply that reduction has not yet occurred, but that it is believed to be impossible in principle. In such a setting, invoking teleology by saying that "the system evolves toward a macro-level goal state" does not resolve the disconnection—it merely relabels it. Teleological framing introduces the appearance of understanding without providing a mechanism, derivation, or structural bridge. It is, in this context, epistemically superficial.

To be sure, teleological language may still offer metaphorical or heuristic value. It can help organize thought or provide linguistic scaffolding for intuition. But in the absence of any workable path from A to B, such modeling does not deepen our understanding, nor does it contribute to theory development. It does not constrain hypotheses, guide mechanism discovery, or offer testable predictions. Its role is non-integrative and unproductive.
By contrast, in cases of weak emergence, there is at least partial overlap between A and B. The macro-level properties described in B arise from the same substrate as A and may be accessed via coarse-graining, simulation, or probabilistic modeling. In these settings, teleological models can serve a powerful filtering or guiding function, helping to narrow the space of plausible micro-level mechanisms.

But in strong emergence, where no such bridge exists—or is claimed to exist even in principle—teleological language becomes a placeholder for ignorance. It signals the absence of explanation while pretending to offer one.

Thus, in genuinely strongly emergent systems—if such systems exist at all—teleological component models do not play a constructive modeling role. They neither illuminate the mechanisms involved nor help bridge the epistemic gap between levels. Their use in this context is at best metaphorical, at worst misleading. Teleology here becomes a linguistic crutch, not a modeling tool. This further undermines the utility of the strong emergence paradigm within scientific theory construction.

7. Reduction, Weak Emergence, and Teleology – Digging Deeper

In the preceding sections, we explored how teleological component models can productively contribute to both reductionist and emergent modeling postures. We now deepen this investigation by examining how the methodological role of teleology reveals a deeper continuity between the paradigms of reduction and weak emergence—two stances often treated as distinct, if not opposed.

Let us recall the key insight established earlier in the paper: *teleology becomes methodologically indispensable precisely at the point where reduction stalls*. When bottom-up causal modeling encounters complexity, intractability, or conceptual opacity, teleological framing offers directionality—a way to reorient the inquiry around potential goals, end-states, or attractor structures. Crucially, such models do not replace mechanistic models but constrain and guide their development. They prune the hypothesis space by specifying outcomes that any plausible mechanism must approximate or achieve.

This same methodological role of teleology applies in both paradigms:

- *In the reductionist paradigm*, teleological modeling helps re-initiate the reductionist chain when it stalls. Knowing the system's goal can suggest likely pathways and mechanisms, limiting the search space for causal explanations.
- *In the weak emergence paradigm*, teleology provides macro-level attractors or organizing principles that guide exploration of the micro-to-macro mapping. It informs our efforts to derive or simulate emergent behavior from known components, even when direct derivation is currently beyond reach.

Thus, although reductionism and weak emergence differ in modeling posture—due to differing levels of epistemic accessibility—the function of teleology in both is strikingly similar. This leads to the following conclusion:

> Reductionism and weak emergence are not opposing paradigms. Rather, they are different modeling stances toward systems at different levels of epistemic accessibility. Emergence could be seen not as the breakdown of reductionism, but a phase in modeling where new concepts and macro-level laws are introduced to guide understanding when lower-level derivation fails, stalls, or appears not practical. Such setbacks might be temporary and further advances in science might allow us to overcome them. The boundary where the reduction breaks down or, we'd better say, stalls is exactly where teleology kicks in. From that point forward, the reductionist search for causal-mechanistic chains leading from micro-level interactions to macro-level outcomes can be reframed as a teleological pursuit: we model the macro-level state as a goal toward which the system appears to be evolving. To get us over that gap we, in effect, are saying, "the goal of system evolution or phenomenon is the state explained or described by the macro-level

concepts and laws, and what is the mechanism realizing the transition to this goal is yet unknown to us." In other words, *emergence increasingly appears to be just an unfinished reduction*.

What follows from this is a key unifying principle:

> *The methodological value of teleology transcends the distinction between reduction and emergence. It is not tied to any particular modeling paradigm but instead serves as a flexible tool of epistemic navigation—one that enables model-building to continue even where direct causal derivation is temporarily blocked*.

By functioning as a filter on the space of explanatory options, teleological modeling allows science to remain provisional, adaptive, and progressive. It offers an avenue through which scientific modeling can remain productive even when formal derivation fails. And it does so without appealing to metaphysical commitments about goals or purposes in nature.

In this light, teleology is best understood not as an antiquated metaphysical claim, but as a resilient and indispensable component of modeling methodology. It reflects the intelligence of inquiry itself—the ability to work backwards from observed or desired outcomes to hypothesize structures, rules, or mechanisms that may realize them.

8. Historical Survey of Theory Reduction and the Role of Teleology

8.1. Purpose and Design

Thus far, we have argued that teleological component models—when properly defined as non-anthropomorphic representations of directional, convergent dynamics—can play a legitimate and even indispensable role in scientific theory construction. We have shown how such models serve a unique epistemic function, particularly at points where mechanistic derivation stalls or where macro-level phenomena resist bottom-up explanation. However, this methodological possibility raises a critical empirical question: *how often has this actually occurred in the historical development of science?*

It could be the case that teleological modeling is theoretically sound but historically rare—an elegant but marginal tool. Alternatively, it may turn out to have been quietly instrumental in many of the major breakthroughs that shaped modern scientific knowledge.

To answer this, we assembled a set of *100 well-documented historical cases of theory reduction or gap-closing* drawn from four domains:

- Physics & Cosmology
- Chemistry
- Biology
- Earth Sciences

Each case records a macro-level phenomenon or theory and the corresponding micro-level (or lower-level) account that eventually bridged the gap. Each case was classified into one of two categories:

- *Scenario 1 (No teleology):* The gap was closed without teleological components playing an instrumental role.
- *Scenario 2 (Teleology instrumental):* Teleological component models were instrumental in framing, guiding, or resolving the modeling challenge.

The following public codebook was used to govern case selection and scoring. This makes the survey design fully auditable and reproducible.

Codebook for the historical survey

Objective

Decide, for each historical reduction case, whether teleological component models were epistemically instrumental in closing the macro→micro (or higher→lower) gap.

Outcomes

- Scenario 2 (Teleology instrumental). At least one of A–C below is satisfied in the historical reasoning.
- Scenario 1 (No teleology). None of A–C is satisfied.

Canonical definitions (used across the paper)

- *Teleology (general).*
  A system exhibits teleological behavior if it displays structured, convergent transitions toward a stable or recurring state ("goal set"), behaving as if that state were its aim, while we remain agnostic about the origin of the goal and avoid anthropomorphism.
- *Teleologically explicit*
  In its standard regime, the principle/law entails directional convergence to a stable or recurring state (e.g., an equilibrium, limit cycle, invariant manifold) for a non-trivial basin of initial conditions.
- *Teleologically implicit*
  At least one holds, without changing the theory's empirical content in its intended regime:
  (1) Equivalent teleological recoding (e.g., stationary-action, geodesic, minimum/maximum principles).
  (2) Conditional attractor under stated conditions (e.g., dissipation, openness, slow-roll).
- *Supporting (compact)*
  Not directional in itself; provides constraints/structure that make convergence possible or robust when combined with other principles.

Scenario-2 triggers (any one suffices)

- *A — Equivalent teleological recoding used*.
  Historical sources show an as-if goal (extremal) formulation was actually used to guide derivations, constrain search, or frame the bridge (e.g., stationary action, maximum entropy), and that it is empirically equivalent to the non-teleological formulation in that regime.
- *B — Conditional attractor reasoning used*.
  Historical sources show attractor/target-set reasoning (equilibria, Lyapunov stability, invariant manifolds, slow-roll, pointer states, virialization, quasi-stationary states) was instrumental in building or validating the bridge in the stated regime.
- *C — Explicit convergence principle used*.
  A directional law (e.g., Second Law, monotone Lyapunov function) was explicitly invoked to derive, constrain, or validate the bridge.

Not sufficient for Scenario 2

- Mere existence of a variational form that was not used historically.
- Pure supporting constraints (symmetries, conservation laws) unless they are part of A or B above.
- Purely ex post teleological gloss with no methodological role in the actual gap-closing.

Evidence standard

Prefer primary sources (papers, monographs, laboratory notes); otherwise authoritative secondary syntheses. Record at least one source evidencing A/B/C. When evidence is mixed, note the branch and give a brief justification.

Procedure

1. Summarize the case (macro theory → micro theory, or higher → lower level).
2. Apply the checklist: A? B? C? (Y/N each).
3. Assign the scenario: Scenario 2 if any of A/B/C = Yes; otherwise Scenario 1.
4. Record the branch(es) and a one-sentence teleology warrant (≤ 25 words).
5. Note sources (minimum one).
6. Flag borderline cases for separate discussion when classification remains uncertain despite best efforts

Inclusion and scope

We include both quantitative and structural/qualitative cases, provided the historical record is sufficient to assess whether A, B, or C was instrumental in the actual reasoning. Cases span laboratory, theoretical, and computational episodes; the unit of analysis is the gap-closing episode, not the lifetime of a field.

8.2. Results and Conclusions

Aggregate results:

- Scenario 1 (no teleology instrumental): 44 / 100
- Scenario 2 (teleology instrumental): 56 / 100

By domain:

Domain	Scenario 1	Scenario 2	Scenario 2 %
Physics & Cosmology (30)	13	17	56.7%
Chemistry (25)	11	14	56.0%
Biology (25)	11	14	56.0%
Earth Sciences (20)	9	11	55.0%
TOTAL (100)	**44**	**56**	**56.0%**

Headline finding. Teleological components—understood non-anthropomorphically and scored strictly by instrumental use—were *prevalent across all four domains*, appearing in a clear *majority* of historical bridges.

How teleology entered the reasoning (A/B/C, qualitatively):

- (B) Attractor/target-set reasoning was the most common mode: appeals to equilibria, invariant sets, limit cycles, virialization, de Sitter/FLRW late-time behavior, quasi-stationary states in galaxies and ecosystems, steady states in kinetics and climate, etc., were used to frame mechanisms, select parameters, or validate the bridge when direct derivations were incomplete.
- (A) Equivalent teleological recoding was frequent, especially in physics and chemistry: stationary-action/geodesic formulations, free-energy minimization, and max-entropy frames were used as *as-if* goal-formulations equivalent to non-teleological mathematics, helping organize derivations and constrain search spaces without positing literal purposes.
- (C) Explicit convergence principles were rarer but decisive when present (e.g., entropy increase toward equilibrium): they provided a directional arrow used directly to connect macro-behavior with micro-mechanisms.

Domain snapshots:

Physics & Cosmology. Instrumental teleology appeared both via A (stationary action, geodesic motion, free-energy/variational frames) and via B (slow-roll inflation as an attractor, virialization in structure formation, pointer-state selection under decoherence). C was less common but present around thermodynamic bridges. The overall pattern is a

blend of constraint-based extremal recodings and regime-specific attractors guiding model choice and validation.

Chemistry. A was prominent in structure and phase-selection (eigenvalue/variational methods, free-energy minimization), while B/C anchored kinetics and equilibrium reasoning (steady-state assumptions, Le Châtelier-type shifts, electrochemical potentials). Many *mechanistic* bridges remained Scenario 1, but more than half leveraged goal-like structures to shape the successful account.

Biology. B dominated: fitness landscapes and ESS in evolutionary theory, canalization/attractor basins in development, homeostasis and circadian limit cycles in physiology and systems biology. Select cases used A (e.g., efficient-coding or objective-maximization frames) to steer hypotheses and inference. The majority outcome indicates that directional organization of macrodynamics has been a routine methodological guide.

Earth Sciences. B again dominated: climate energy-balance equilibria, thermohaline multiple equilibria, tectonic cycling, geomorphic quasi-equilibria, ecosystem regime-shifts and resilience as attractor-basin problems. Purely mechanistic derivations (Scenario 1) are common in sub-fields, yet more than half of the bridges made instrumental use of target-state reasoning.

Conclusions:

1. Pervasiveness without anthropomorphism. *Teleology, understood as as-if goal-structure (A) or genuine convergent dynamics (B/C), is methodologically pervasive across the natural sciences when scientists confront unfinished reduction*. No claims of literal purpose or backward causation are required.
2. Two complementary roles. Teleological components contribute in two systematic ways:
    - as equivalent global-constraint recodings that organize and focus derivations (A), and
    - as attractor-based guides that stabilize, select, or validate mechanisms under realistic regimes (B/C).
3. Implication for practice. When micro-derivations stall or search spaces explode, teleological modeling provides actionable structure—target sets, extremal principles, robustness arguments—that accelerate discovery and help close the gap.
4. Caveats. Scenario 2 classification required documented instrumentality (not ex-post gloss). Some cases admit multiple branches (A with B/C); we record the branch(es) used rather than force a single label. Selection and documentation biases are possible; the codebook and per-case warrants (provided in the appendix template) are designed to make replication straightforward.

Bottom line:

On this independent, codebook-driven survey, **56%** of historical gap-closings used teleological components instrumentally.

Teleology, in the non-anthropomorphic, methodological sense defined here, is neither peripheral nor exceptional—it is a regular tool of successful scientific practice. *Scientific progress has frequently been guided by teleological models that impose directional constraints, structure explanatory search, and enable modeling when mechanistic understanding is incomplete*.

9. Are All Major Theories in Natural Sciences Teleological?

In the previous section, we examined the role of teleological models in closing explanatory gaps within scientific theories. We showed that goal-directed frameworks—far from being obsolete or unscientific—often serve as essential scaffolding when mechanistic models are incomplete or unavailable. But this raises a deeper question: *Is teleology merely a temporary tool useful only at the frontiers of knowledge, or is it embedded in the very foundations of science itself?* In other words, once a theory has matured and its gaps are closed, does teleology retreat, leaving behind only mechanical causation? Or do teleological models continue to shape how we conceptualize the world—even at the level of a theory's most basic postulates and principles?

9.1. A Survey of Theories: Purpose and Design

This section presents a systematic survey of major dynamic theories in physics, astronomy, and cosmology, aimed at assessing the historical and structural role of teleological modeling in scientific theory formation. The motivation behind this effort stems from the central claim of this paper: that teleological considerations—understood non-anthropomorphically as directional or goal-driven modeling—have not merely coexisted with mechanistic approaches but have often played a constructive and even indispensable role in advancing scientific understanding.

The survey was designed to test this hypothesis by examining the *foundational postulates and first principles* of a carefully selected set of *14 major dynamic theories*. These theories span the domains of physics, astronomy, and cosmology—a scope deliberately chosen for its proximity to the epistemic roots of the natural sciences. These three fields together constitute what is often viewed as the most fundamental explanatory layer in the reductionist hierarchy. Under the mechanistic-reductionist paradigm, other sciences—chemistry, biology, earth sciences—are expected to ultimately reduce to physics, and physics itself is expected to reduce to a finite set of postulates or principles. By targeting the theories nearest to this foundational core, our analysis aims to scrutinize the base layer to which all other scientific domains are, in principle, reducible. If teleological models are

found to play a substantive role even at this deepest level, the implications for scientific methodology are profound.

The term "dynamic" is used here to denote theories that describe the *evolution or change of physical systems over time*, as opposed to theories concerned solely with static constraints, mathematical symmetries, or taxonomies. This filter excludes important but non-dynamic frameworks such as gauge theory, special relativity (as a kinematic theory), and group-theoretic classification schemes.

Each theory included in the survey was analyzed at the level of its core assumptions—those axiomatic or postulated elements that ground the theory and are not, at present, reducible to deeper explanatory mechanisms. For each of these foundational elements, we asked a simple but powerful question:

> *Does this principle encode or presuppose a goal-directed convergence toward a particular class of states over time?*

In cases where the answer was affirmative, we further distinguished between three kinds of teleological modeling:

- *Teleologically Explicit.* A postulate/principle is *teleologically explicit* when, in its standard domain of application, it entails directional convergence to a stable or recurring state (e.g., an equilibrium, limit cycle, or invariant manifold) for a non-trivial basin of initial conditions.

- *Teleologically Implicit.* A postulate/principle is *teleologically implicit* when at least one of the following obtains, without changing the theory's empirical content in its intended regime:

    - *Equivalent teleological recoding:* There exists an empirically equivalent formulation that represents the behavior "as-if" a goal is extremized or satisfied (e.g., stationary-action, geodesic, minimum principles).
    - *Conditional attractor:* Under standard, stated conditions of the principle's regime (e.g., dissipation, openness, slow-roll), the dynamics possess an attracting goal set with a non-trivial basin.

- *Teleologically Supporting.* A postulate/principle is not directional in itself; however, it provides constraints/structure that make convergence possible or robust when combined with other principles.

All remaining principles were classified as *non-teleological*, meaning they did not exhibit or support directional modeling under our criteria.

The classification was based on the *behavior predicted by the theory*, not merely on its verbal form. This methodological stance is critical. Many physical postulates appear purely descriptive in wording but function teleologically when applied: they generate structured, convergent behavior in the modeled system. Our aim was to capture such functional teleology in a rigorous and philosophically neutral way, using a definition that avoids appeals to intention, consciousness, or purpose in any anthropomorphic sense.

The full list of theories includes:

I. Physics – Dynamic Theories
1. Newtonian Mechanics (Classical Mechanics)
2. Classical Electrodynamics
3. Thermodynamics + Statistical Mechanics (Time-dependent formulations)
4. Quantum Mechanics (non-relativistic)
5. Quantum Field Theory (QFT)
6. General Relativity (GR)
7. Fluid Dynamics / Continuum Mechanics
8. Plasma Physics

II. Astronomy – Dynamic Theories
9. Celestial Mechanics
10. Stellar Evolution Theory
11. Galactic Dynamics

III. Cosmology – Dynamic Theories
12. Big Bang Cosmology (ΛCDM Model)
13. Inflationary Cosmology
14. Structure Formation Models

For each theory, we examined its explicit postulates or foundational assumptions—those elements considered irreducible within the current state of knowledge and treated as given in the theory's construction. These were not necessarily derived from first principles but rather *define* the operational structure of the theory itself.

To illustrate:

- In **Newtonian Mechanics** (law of inertia) and in **Celestial Mechanics** (universal gravitation), pairing inertia with gravity yields structured, recurrent trajectories confined to invariant sets (e.g., bounded orbits)—not generic convergence absent dissipation. The *implicit* tag here rests on equivalent extremal/geodesic recoding (action principles), rather than on attractor-like approach.
- In **Thermodynamics**, the **Second Law**, asserting that entropy increases in closed systems, was classified as *teleological (explicit)*, since it defines a system-wide directional trend toward a maximum-entropy state.
- In **Quantum Mechanics**, the unitary evolution governed by the Schrödinger equation was originally judged non-teleological. However, the inclusion of

measurement postulates and the Born rule—which describe convergence to definite outcomes—were recognized as *teleological (implicit)* or *supporting*, depending on their role in interpretation.
- In **Cosmic Inflation**, the postulate that space undergoes rapid exponential expansion driven by a scalar field potential was judged *teleological (explicit)*, due to the convergence toward a vacuum-like state that sets up the initial conditions of the observable universe.

Each classification was based not on the historical intent behind the theory nor the verbal form of the postulate, but on the *behavior that the model predicts and structurally enforces*. A postulate was marked as teleological if it governed transitions that reliably steered systems toward stable, recurring, or endpoint states in a way that conformed to our non-anthropomorphic definition of goal-driven behavior.

The complete list of theories, postulates and first principles along with their classification and justification are included in the Appendix.

What follows in the next subsection is a comprehensive presentation of the full results, based on this classification system, followed by an interpretive discussion of what these findings mean for the role of teleological reasoning in the development of scientific knowledge.

9.2. Results and Conclusions

This section synthesizes the results of the survey of 56 postulates/first principles across 14 dynamic theories under the canonical definitions of *teleological*, *teleologically explicit*, *teleologically implicit*, and *supporting*.

Headline results

- *Explicit teleology: 4 / 56 (7.1%)*
  Laws/principles that, in their standard domain, *entail directional convergence* to a stable or recurring state (e.g., the Second Law; slow-roll/inflationary attractors; hydrostatic relaxation in stellar interiors).
- *Implicit teleology: 25 / 56 (44.6%)*
  Principles that either (i) admit an *empirically equivalent teleological recoding* (e.g., stationary-action, geodesic, minimum principles), or (ii) exhibit *attractors under stated regime conditions* (dissipation, openness, slow-roll, coarse-graining).
- *Supporting (non-directional enablers): 11 / 56 (19.6%)*
  Constraints/symmetries/constitutive structure that make convergence possible or robust when combined with other principles.
- *No teleology: 16 / 56 (28.6%)*

Theory-level prevalence. Every domain examined contains teleological components: **14 / 14 theories (100%)** include at least one postulate that is either explicit or implicit in the above sense. Teleology is therefore *methodologically pervasive* at the foundations, even if explicit convergence laws are comparatively rare. Please refer to Appendix A for details.

Where teleology shows up (and how)

1. *Explicit* (rare but strong)

   Clear, regime-stable directionality toward an equilibrium or recurring set:
   - Thermodynamics/Stat Mech: typical approach to equilibrium via the Second Law (probabilistic reading).
   - Inflationary Cosmology: slow-roll solutions and the exponential phase function as attractors over wide basins.
   - Stellar Evolution: relaxation toward hydrostatic (and thermal/transport) equilibria within broad initial ranges.

2. *Implicit via equivalent teleological recoding (common)*

   - Variational/Geodesic frameworks: Newtonian mechanics (standard Lagrangian), electromagnetism (field action), QFT (Lagrangians/path integrals), and GR (Einstein–Hilbert action; geodesic motion) all admit as-if extremization formulations that are *empirically equivalent* to their differential forms. Under our canonical definition, these count as *teleologically implicit*. This does not assume temporal relaxation; it registers the goal-like constraint structure.

3. *Implicit via conditional attractors (common, but regime-scoped)*

   - Fluids/Plasmas: with viscosity/resistivity and appropriate boundaries/forcing, Navier–Stokes/MHD flows relax to steady states or low-dimensional attractors; at high Reynolds or collisionless limits, convergence may fail or become statistical/coarse-grained.
   - Open Quantum Systems/Measurement: collapse theories or decoherence dynamics select pointer/eigenstates (attractor-like behavior in the open-system regime).
   - Cosmology (ΛCDM): late-time FLRW/de Sitter behavior functions as an attractor under $\Lambda>0$ and standard matter content.
   - Structure Formation/Galactic Dynamics: gravitational instability drives collapse/virialization; violent relaxation and mixing yield quasi-stationary macro-states (attractor-like at coarse-grained scale).

What these results establish (and what they do not)

- Established
    - Teleological structure is not confined to biological or "edge-case" contexts: it appears widely across foundational physics via either equivalent extremal/geodesic recodings or regime-conditioned attractors.
    - Every theory in the survey exhibits at least one teleological component; overall, ~52% of all postulates are teleological (explicit + implicit), with a further ~20% playing a supporting role.
- Not claimed
    - No appeal to literal purposes, design, or backward causation.
    - Implicit teleology via variational recoding does not assert temporal "seeking" of minima; it asserts an equivalent 'as-if' goal formulation of the same empirical content.
    - Attractor claims are regime-scoped (e.g., dissipation, openness, slow-roll, coarse-graining) and do not imply convergence outside those conditions.
    - In conservative dynamics (e.g., undamped Hamiltonian systems), neutral cycles and invariants remain non-convergent and are not counted as explicit teleology.

Methodological upshot

These findings sharpen the paper's central thesis: teleology is methodologically indispensable precisely where reduction stalls, but it is also integrated into mainstream theory in two systematic ways—through equivalent extremal recodings and through conditional attractors. The former clarifies why teleological language has long been productive in classical and modern field theories; the latter explains teleology's practical necessity in open, dissipative, and cosmological regimes where long-time behavior is organized by attracting sets. Together, they support a balanced conclusion: teleological models are neither exotic nor optional add-ons; they are routine tools of theory with clear, non-anthropomorphic semantics.

The implication is clear: *teleological modeling is not a fringe or auxiliary feature of scientific reasoning*, nor is it limited to periods of theoretical incompleteness. Rather, it appears to be a deeply embedded element in the very foundations of our most successful and enduring scientific theories. From the Second Law of Thermodynamics, which describes the universal drive toward maximal entropy, to the principle of cosmic inflation, which specifies a rapid directional expansion of space toward a vacuum-dominated state, modern science is saturated with principles that act "as if" systems evolve toward predefined outcomes.

This finding challenges the assumption that mechanistic models alone account for scientific progress or explanatory power. It suggests that *teleological concepts are not just*

useful at the margins of scientific inquiry, where mechanisms are still unknown, but play an essential role in how science frames, structures, and interprets the dynamics of reality.

In the next subsection, we reflect on what this means for our understanding of scientific modeling itself, and whether the standard dichotomy between "mechanistic" and "teleological" thinking can continue to hold.

9.3. Rethinking Scientific Modeling: Beyond the Mechanism–Teleology Divide

The findings of our survey compel a reexamination of one of science's most enduring conceptual divides: the dichotomy between mechanistic and teleological models. Traditionally, mechanistic models have been treated as the gold standard of scientific rigor—models that reduce system behavior to local interactions, deterministic equations, and bottom-up causation. Teleological models, by contrast, have often been relegated to the status of heuristic, metaphorical, or even unscientific, due to their historical association with purpose-driven or anthropocentric thinking.

But the prevalence of teleological features in the foundational postulates of science, as demonstrated in Section 9.2, suggests that this divide is no longer tenable—at least not in its conventional form.

The distinction between mechanistic and teleological models is not one of truth vs. metaphor, but of modeling stance. Mechanistic models emphasize *proximal causes*—they account for how a system evolves given its current state and physical interactions. Teleological models, in contrast, highlight *convergent outcomes*—they describe the *directional behavior* of a system, especially when that system tends to evolve toward a stable, recurring, or extremal state. The two approaches are not mutually exclusive. In fact, the most robust scientific models often integrate both.

The Second Law of Thermodynamics is a paradigmatic case. It is mechanistic in that it emerges from assumptions about microstate statistics and the conservation of energy, yet it is also teleological in that it governs the *direction of change*—toward maximum entropy. Quantum mechanics is another case in point. The unitary Schrödinger evolution is mechanistic, but the measurement postulates are explicitly convergent, funneling superpositions toward definite outcomes.

This dual character becomes even more apparent in cosmology. The inflationary epoch is modeled as a system evolving toward a vacuum-dominated attractor—a structure deeply teleological in form, yet derived from mechanistic equations. Such theories are not compromises between conflicting styles of modeling—they are examples of how *directionality and mechanism can operate in tandem* within a coherent scientific framework.

Thus, rather than upholding a binary opposition between mechanistic and teleological modeling, it is more productive to view these as *complementary strategies* for understanding systems at different levels of epistemic access. Mechanistic component models are local, granular, and detailed. Teleological component models are global, structural, and outcome-oriented. One addresses the "how," the other the "where to." In dynamic systems where full mechanistic reduction is impossible or incomplete—as is frequently the case—teleological principles offer essential structure.

Our findings suggest that teleology is not an artifact of gaps in models, but a legitimate and intrinsic feature of how scientific theories describe change. It is not something that must be discarded once a mechanistic model is available, but something that continues to co-define the conceptual architecture of science.

Conclusion – Teleology Rehabilitated

This paper has defended the legitimacy and indispensability of teleological modeling in the natural sciences—not as a mystical or pre-scientific relic, but as a rigorous and philosophically grounded component of scientific reasoning. By reframing teleology as non-anthropomorphic goal-directedness—defined as directional convergence toward stable or extremal states—we have shown that many foundational principles in physics, astronomy, and cosmology satisfy this criterion.

Our historical survey of theory reductions demonstrated that teleological models have played an instrumental role in bridging explanatory gaps where mechanistic accounts were absent, stalled, or incomplete. But more surprisingly, our analysis of foundational postulates in 14 major dynamic theories revealed that teleological assumptions are not confined to the edges of scientific knowledge—they are built into the very core.

Out of 56 postulates examined, 29 (51.8%) exhibited teleological structure (explicit or implicit). Every one of the 14 theories surveyed contained at least one such postulate. This empirical result upends the prevailing assumption that teleological reasoning is a temporary scaffold to be discarded once mechanistic models are available.

Instead, we propose a reversal of that narrative. Teleological principles—such as convergence toward minimal energy, maximal entropy, or vacuum states—often underwrite the success of mechanistic frameworks. What appears as autonomous bottom-up causation frequently relies on statistical, variational, or boundary-driven assumptions that encode directional structure. These assumptions are best understood not as heuristic crutches, but as conceptually teleological. And a closer look reveals that directionality and mechanism often operate *in tandem* as complementary component models of rich scientific theories.

Moreover, rather than treating teleology as a complementary or secondary modeling strategy, we suggest it may be *dominant*: the source from which many mechanistic

explanations draw their force. This view reframes mechanistic models as structurally embedded within broader goal-directed frameworks.

Properly understood, teleological modeling is not a retreat from scientific rigor, but a recognition of science's own evolving modeling repertoire. By embracing a pluralistic methodology—one that respects both causal mechanisms and directional constraints—science can better grasp the complexity of dynamic, emergent, and boundary-sensitive systems.

This project does not claim that all systems are inherently goal-driven in an ontological sense. It claims instead that *teleological modeling*—when used with epistemic discipline and stripped of needless anthropocentric assumption—remains a powerful and legitimate tool for advancing scientific knowledge. To deny this is not to uphold scientific rigor, but to constrain it unnecessarily.

Teleology in science should neither be dismissed as obsolete nor conflated with mysticism. It is, and has always been, one of the ways science sees.

For position in literature please refer to Appendix B.

Survey of 14 Theories – Details

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
1	Newtonian Mechanics	1	Law of Inertia	No — Persistence principle; no convergence or goal set.	No
1	Newtonian Mechanics	2	F = ma	Implicit — Equivalent teleological recoding: standard Lagrangian form (L=T−V) yields Euler–Lagrange equations equivalent to F=ma; 'as-if' extremize action. Equivalence holds for smooth forces on a fixed background with differentiable trajectories; no dissipation is assumed.	Yes (implicit)
1	Newtonian Mechanics	3	Action and Reaction symmetry	No — Symmetry of interactions; does not entail directional approach.	No
1	Newtonian Mechanics	4	Absolute space and time	No — Background structure; not an evolution law.	No
2	Classical Electrodynamics	1	Electric charges create electric fields	Supporting — Ontological field postulate; enables but does not by itself produce convergence.	Yes (supporting)
2	Classical Electrodynamics	2	Faraday's and Ampere-Maxwell Laws	Implicit — Conditional attractor: with resistance/lossy media or RLC circuits, dynamics relax to	Yes (implicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
				steady states or periodic attractors.	
2	Classical Electrodynamics	3	Speed of light is constant	No — Kinematic constraint; no approach to a goal set.	No
2	Classical Electrodynamics	4	Charge conservation	Supporting — Conservation law; supports stability but is not directional by itself.	Yes (supporting)
2	Classical Electrodynamics	5	EM Lagrangian	Implicit — Equivalent teleological recoding: extremizing the electromagnetic action (Euler–Lagrange) is empirically equivalent to Maxwell's equations in the standard classical/relativistic regime; no temporal "seeking" is implied.	Yes (implicit)
3	Thermodynamics + Statistical Mechanics	1	First Law: Energy conservation	No — Bookkeeping identity; no directional trend.	No
3	Thermodynamics + Statistical Mechanics	2	Second Law: Entropy increases	Explicit — Typical macroscopic evolution toward equilibrium (with fluctuations) from wide basins.	Yes (explicit)
3	Thermodynamics + Statistical Mechanics	3	Equal a priori probability	Supporting — Statistical assumption underpinning entropy methods; not itself a dynamical approach.	Yes (supporting)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
3	Thermodynamics + Statistical Mechanics	4	Statistical ensembles	Supporting — Modeling framework that enables relaxation descriptions; not a dynamical law per se.	Yes (supporting)
4	Quantum Mechanics	1	Wavefunction in Hilbert space	No — State-space axiom; no convergence under unitary dynamics.	No
4	Quantum Mechanics	2	Schrödinger equation	No — Unitary, time-reversible evolution; no attractor without openness.	No
4	Quantum Mechanics	3	Born Rule (probabilistic measurement outcomes)	Implicit — Conditional attractor: in collapse models or open-system decoherence, states tend toward eigen/pointer states.	Yes (implicit)
4	Quantum Mechanics	4	Observables are Hermitian operators	No — Measurement operators as constraints; not a convergence statement.	No
5	Quantum Field Theory (QFT)	1	Fields are fundamental entities	No — Ontological thesis about fields; not a directional evolution.	No
5	Quantum Field Theory (QFT)	2	Quantization via commutation relations	No — Kinematic quantization rule; no approach-to-set behavior.	No
5	Quantum Field Theory (QFT)	3	Lorentz invariance	No — Symmetry principle; not a convergence claim.	No
5	Quantum Field Theory (QFT)	4	Lagrangian formalism with path integrals	Implicit — Equivalent teleological recoding: stationary-	Yes (implicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
				action/Lagrangian formulation provides an equivalent 'as-if extremization' recoding. Equivalent to Euler–Lagrange field equations in the classical limit; in the path-integral, stationary-phase selects classical trajectories (no teleonomic "seeking").	
6	General Relativity (GR)	1	Equivalence principle	Implicit — Equivalent teleological recoding: free fall recoded as geodesic motion (extremal proper time). Equivalence holds for freely falling test bodies in curved spacetime absent non-gravitational forces.	Yes (implicit)
6	General Relativity (GR)	2	General covariance	No — Form-invariance principle; no directional approach.	No
6	General Relativity (GR)	3	Einstein field equations	Implicit — Equivalent teleological recoding: field equations from extremizing the Einstein–Hilbert action. Equivalence holds given standard variational setup (fixed boundary data / Gibbons–Hawking–York term as required).	Yes (implicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
7	Fluid and Plasma Dynamics	1	Continuum approximation	No — Modeling assumption; no convergence content.	No
7	Fluid and Plasma Dynamics	2	Conservation of mass, momentum, energy	Supporting — Conservation constraints; enable but do not ensure relaxation.	Yes (supporting)
7	Fluid and Plasma Dynamics	3	Constitutive relations	Implicit — Conditional attractor: with viscosity/closures, flows relax to steady or periodic states in standard regimes.	Yes (implicit)
7	Fluid and Plasma Dynamics	4	Navier–Stokes equations	Implicit — Conditional attractor: viscous, bounded, appropriately forced flows exhibit steady states/attractors; turbulence is an exception.	Yes (implicit)
8	Plasma Physics	1	Plasma is a quasi-neutral gas of charged particles	Supporting — Descriptive setup; enables collective relaxation phenomena.	Yes (supporting)
8	Plasma Physics	2	Collective behavior dominates	Implicit — Conditional attractor: Landau damping/phase mixing yield macroscopic relaxation (often coarse-grained).	Yes (implicit)
8	Plasma Physics	3	Described by Vlasov or MHD equations	Implicit — Conditional attractor: MHD with resistivity/viscosity relaxes; Vlasov approaches quasi-	Yes (implicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
				stationary states under coarse-graining.	
8	Plasma Physics	4	Obeys Maxwell's equations	Supporting — Field coupling provides structure; not goal-directed on its own.	Yes (supporting)
9	Celestial Mechanics	1	Bodies interact via Newtonian gravity or GR	Implicit — Equivalent teleological recoding: Newtonian gravity derives from L=T−V; in GR, free fall follows geodesic extremization. Generic conservative two-body motion is bounded/periodic (recurrent), not convergent; no dissipative attraction is claimed.	Yes (implicit)
9	Celestial Mechanics	2	Initial conditions determine trajectories	No — Well-posedness/uniqueness statement; not directional.	No
9	Celestial Mechanics	3	Conservation of energy and angular momentum	Supporting — Conservation constraints; support stability without implying attraction.	Yes (supporting)
9	Celestial Mechanics	4	Point-mass approximation	Supporting — Idealization that enables tractable dynamics; not a convergence claim.	Yes (supporting)
10	Stellar Evolution	1	Hydrostatic equilibrium	Explicit — Stellar interiors relax toward hydrostatic balance from a wide basin.	Yes (explicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
10	Stellar Evolution	2	Nuclear fusion drives energy generation	Implicit — Conditional attractor: fusion plus radiative losses drive evolution along quasi-steady tracks (e.g., main sequence).	Yes (implicit)
10	Stellar Evolution	3	Energy transport by radiation or convection	Implicit — Conditional attractor: transport processes drive approach to thermal/radiative-convective equilibria.	Yes (implicit)
10	Stellar Evolution	4	Equation of state for stellar material	No — Constitutive relation; not directional.	No
11	Galactic Dynamics	1	Evolution via gravity and conservation laws	Implicit — Conditional attractor: violent relaxation and mixing lead to quasi-stationary states at coarse-grained level.	Yes (implicit)
11	Galactic Dynamics	2	Distribution function governed by Vlasov/Boltzmann equation	Implicit — Conditional attractor: approach to stationary/coarse-grained equilibria in practice; fine-grained dynamics mix.	Yes (implicit)
11	Galactic Dynamics	3	Poisson equation for gravitational potential	Implicit — Equivalent teleological recoding: arises from variational gravitational energy functional.	Yes (implicit)
11	Galactic Dynamics	4	Dark matter as collisionless background	Implicit — Conditional attractor: DM-shaped potentials guide hierarchical assembly toward virialized halos (macro-level).	Yes (implicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
12	Big Bang Cosmology (ΛCDM)	1	Cosmological principle (homogeneity and isotropy)	Supporting — Symmetry assumption that frames models; not a dynamical target by itself.	Yes (supporting)
12	Big Bang Cosmology (ΛCDM)	2	Einstein field equations + FLRW metric	Implicit — Conditional attractor: with Λ>0 and standard matter content, FLRW/de Sitter act as late-time attractors.	Yes (implicit)
12	Big Bang Cosmology (ΛCDM)	3	Dark matter and energy as effective components	Implicit — Conditional attractor: Λ domination and cold DM dynamics steer expansion/structure growth directionally.	Yes (implicit)
12	Big Bang Cosmology (ΛCDM)	4	Hot, dense early universe	Supporting — Past boundary condition; sets arrow-of-time context but not a convergence target.	Yes (supporting)
13	Inflationary Cosmology	1	Scalar inflaton field	Explicit — Slow-roll solutions are attractors over wide basins of initial conditions.	Yes (explicit)
13	Inflationary Cosmology	2	Quantum fluctuations seed structure	No — Stochastic seeding; not directional by itself.	No
13	Inflationary Cosmology	3	Inflation solves flatness/horizon problems	Implicit — Conditional attractor: slow-roll dynamics smooth curvature/horizon variations (convergent macro-outcome).	Yes (implicit)
13	Inflationary Cosmology	4	Rapid exponential	Explicit — Exponential expansion with a well-	Yes (explicit)

Theory #	Theory	Postulate #	Postulate / Principle	Analysis & Justification	Teleological Model?
			expansion phase	defined end (ε→1) under slow-roll conditions; robust attractor.	
14	Structure Formation	1	Initial perturbations evolve via gravity	Implicit — Conditional attractor: gravitational instability drives collapse toward bound/virialized structures from broad basins.	Yes (implicit)
14	Structure Formation	2	Linear and nonlinear growth	Implicit — Conditional attractor: nonlinear evolution towards halos/filaments acts as macro-level attractor (virialization).	Yes (implicit)
14	Structure Formation	3	Cold dark matter dominance	Implicit — Conditional attractor: cold DM hierarchy directs assembly toward stable halos; directional at macro scale.	Yes (implicit)
14	Structure Formation	4	Gravity from GR or Newtonian limit	Implicit — Equivalent teleological recoding: underlying gravity (Newtonian/GR) has variational/geodesic formulations; 'as-if extremization'.	Yes (implicit)

Position in Literature

Aim and scope

This appendix situates the paper's non-anthropomorphic account of teleology—formalized via explicit (directional convergence) and implicit (either equivalent teleological recoding or conditional attractors)—within four major strands: (i) mechanistic explanation (Machamer–Darden–Craver), (ii) constraint-based/asymptotic explanation (Batterman and successors), (iii) accounts of emergence (Anderson; Kim; Wilson; others), and (iv) teleonomy/organizational accounts in biology (Mayr; Mossio & Moreno). The goal is clarity about compatibility, division of labor, and added value rather than priority claims.

Working vocabulary (abbreviated):

Teleologically explicit: a principle entails directional convergence to a stable/recurring state for a non-trivial basin.
Teleologically implicit (A): there is an empirically equivalent "as-if goal" formulation (e.g., stationary action, geodesics, max-entropy).
Teleologically implicit (B): under stated conditions (e.g., dissipation, openness, slow-roll), the dynamics possess an attracting goal set.
Supporting: non-directional constraints/structures that make convergence possible or robust when combined with other principles.

1) Mechanistic explanation (Machamer–Darden–Craver, MDC)

Core view. Explanations cite organized **entities and activities** that produce a phenomenon; evaluation turns on component localization, productive continuity, and manipulability.
Relation to this paper. Our teleology is a **modeling stance** that *guides* mechanism discovery when reduction is stalled. It does **not** compete with MDC; it **prioritizes search** by fixing target sets (goal states, attractors) and filtering mechanistic candidates to those capable of realizing the required convergence profile or obeying the relevant extremal constraint.
Added value. When many mechanistic proposals are underdetermined by data, teleological structure functions as a **filter and stabilizer**, narrowing the hypothesis space and increasing the prior plausibility of candidate mechanisms.

2) Constraint-based / asymptotic explanation (Batterman)

Core view. Many successful explanations appeal to **constraints and asymptotic regimes** (universality classes, singular limits) where macroscopic behavior is organized by **global structure**, not fine microdetails.
Relation to this paper. Our **implicit-A** (equivalent extremal recodings) and **implicit-B** (attractors) naturally instantiate constraint-based explanation: both capture how **global structure** (an extremum principle or an invariant/attractor set) controls behavior. We add an explicit **as-if goal** reading that clarifies why constraint-based methods are so productive: they reveal the **target sets** around which modeling organizes.

3) Emergence

Core landscape. Anderson's "More is different" defends the autonomy of higher-level regularities; Kim and others press for physicalist discipline while rejecting strong emergence.
Relation to this paper. We treat **weak emergence as unfinished reduction**. Teleological models provide **operational scaffolds** (targets, extremal constraints) that organize work at the boundary of present derivational power. They are **regulative** rather than ontic: indispensable for discovery now, replaceable by detailed derivation when/if it becomes available.

4) Teleonomy & organizational accounts (biology and beyond)

Core view. Biological goal-talk is legitimate when understood as **teleonomy** (Mayr) or **organizational closure** in far-from-equilibrium systems (Mossio & Moreno): systems maintain themselves by producing the conditions of their own persistence.
Relation to this paper. Our framework **generalizes** such non-anthropomorphic goal-structure beyond biology. We keep the **formal** criterion (convergent dynamics or equivalent goal recoding) while remaining agnostic about agency or normativity. The same structure applies in physics and cosmology (e.g., slow-roll attractors, stationary-action formulations) and in engineered systems (control/feedback).

Summary map (compatibilities at a glance)

- **MDC (mechanistic)**: teleology = **search guide** and **filter** for mechanisms; not a competitor.
- **Constraint-based**: teleology = **explicit articulation** of target-set/optimization structure that makes asymptotic explanations work.
- **Emergence**: teleology = **method at the boundary** of current derivational power; a **regulative heuristic** for gap-closing.
- **Teleonomy/organizational**: teleology = **formal convergence** that extends beyond living systems with a clean, non-anthropomorphic semantics.

What this paper contributes

1. **Operational clarity.** A precise, two-track notion of **implicit** teleology—**equivalent recoding** (A) and **conditional attractors** (B)—plus **explicit** and **supporting** categories.
2. **Bridging vocabulary.** A single framework that interfaces with mechanistic, constraint-based, emergence, and organizational literatures **without collapsing** into any one of them.
3. **Methodological payoff.** Teleology identified as a **reliable research heuristic**: it constrains hypothesis spaces, stabilizes inference, and accelerates micro-level closure where direct derivations are presently infeasible.

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